1213112

PATENT SPECIFICATION

(11) 1213112

DRAWINGS ATTACHED

(21) Application No. 3861/69 (22) Filed 23 Jan. 1969
(31) Convention Application No. 705 546
(32) Filed 14 Feb. 1968 in
(33) United States of America (US)
(31) Convention Application No. 714 730
(32) Filed 20 March 1968 in
(33) United States of America (US)
(45) Complete Specification published 18 Nov. 1970
(51) International Classification F 01 k 13/00 B 65 g 5/00
(52) Index at acceptance

F1G 1A
F1Q 11B5 11C
F4P 1A1X 1B3

(54) METHOD AND APPARATUS FOR INCREASING THE EFFICIENCY OF ELECTRIC POWER GENERATING PLANTS

(71) I, WILLIAM JOSEPH LANG, a citizen of the United States of America, of 623 Dawes, Libertyville, Illinois 60048, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and apparatus for conserving energy for use in generating electricity.

It is known that the cost and efficiency of electrical power generation can be improved in certain areas by an integrated operation of primary and auxiliary generating systems. Where irregular demand would impose a low load factor on a single generating system a smaller auxiliary system is often used to improve the load factor and efficiency of the primary system which produces the majority of the load. Such a system provides additional power during peak demand periods, a valuable ready reserve, and a source of emergency power. Various power sources are used to drive the auxiliary generating systems including pumped hydro-storage and compressed air storage. Low cost electrical power is used to pump water into elevated storage or to compress air for storage in mined underground salt cavities. The elevated water or compressed air is later used as a source of energy for driving power generating systems during peak demand periods. The resulting auxiliary power is therefore produced at a higher incremental cost as a result of energy lost in conversion but may provide overall cost reductions for electrical generation for the integrated system. Overall cost reductions of as much as 30% in electricity generation have been reported by use of a combined systems of thermal generating plants with pumped hydro-storage auxiliary generating systems. The savings result from improving the load factor of primary generating plant, providing valuable and required ready reserves and deferring the need for expansion of the base load generating system. Energy storage-type auxiliary systems may serve an additional valuable function by absorbing surplus power during sudden load changes for maintaining frequency stability of the electrical output of the primary generating and distribution system. A further impontant consideration is the incalculable value of auxiliary systems as emergency generating sources during power failures.

According to one aspect the present invention provides a method for conserving energy in which gas is compressed and stored in a subterranean reservoir by means of electric power during periods of relatively low electrical load requirement and the gas stored under pressure is withdrawn and used to drive a prime mover to generate electricity during periods of relatively high electrical load requirement, characterized by the fact that the gas is introduced into, stored in and withdrawn from the reservoir while it is held under hydrostatic pressure which does not significantly change and which is sufficient to drive the prime mover.

According to a second aspect the present invention provides a system for conserving energy comprising at least one subterranean storage reservoir, an electrical generating facility, a gas compressor motivated by electricity from said facility, a conduit extending from said reservoir to the surface thereabove for injecting gas from said compressor into said reservoir, means for withdrawing gas from the reservoir, a prime mover operatively connected to the withdrawn gas, and electrical

[P

generating means operatively connected to said prime mover, characterized by means for maintaining said reservoir under superatmospheric hydrostatic pressure which does not change significantly during injection, storage and withdrawal of the gas.

Natural underground artesian aquifers or depleted natural liquid or gaseous hydrocarbon reservoirs, i.e. porous rock formations of relatively high porosity and permeability are utilized as the reservoirs to provide storage into which compressed air or other gas is introduced, stored and withdrawn under hydrostatic pressure which does not significantly change. The pore spaces of such reservoirs are commonly occupied by water which may be displaced by injecting compressed gas at pressures slightly in excess of natural hydrostatic pressure. Reservoirs of this type are known which are capable of storing as much as several billion cubic feet, and gas can be injected or withdrawn at a relatively constant pressure as regulated by the natural hydrostatic pressure of the formation. The reservoir acts like a large elastic chamber, expanding and contracting to accommodate the amount of gas stored due to the movement of water caused by injection and withdrawal of gas. Thus, gas can be compressed and stored during periods of low electrical demand or when low cost electrical power is available and withdrawn under substantially constant pressure during high electrical demand periods to run a prime mover as a power supply for electrical generation. The expense of construction for such a secondary power generating system is greatly reduced over existing methods of constructing surface reservoirs as in the case of pumped hydro-storage peak generating units or excavated underground storage of compressed air in salt formations. Site availability for developing the described storage and secondary generating systems is limited to areas where favourable conditions exist but are more abundant and widespread geographically than either sites suitable for pumped hydro-storage systems or salt cavity, compressed air systems. Where conditions are favourable as to the locations of the primary power plant, second storing-generating system and load centres, the invention will improve the economics over a power plant by improving the load factor of existing distribution systems and deferring construction of additional distribution capacity. Reservoir pressures of about 2800 to 210,000 grams per square centimeter are suitable for the purposes of this invention.

Energy may be stored during low load requirements of a power generating plant by using the excess power available to compress gas such as air and introducing it under high pressure into a subterranean salt or other gas impermeable cavity or reservoir which is maintained under hydrostatic pressure which does not significantly change during introduction, storage and withdrawal of the gas. The cavity is in communication with a water reservoir at the surface of the ground so that the hydrostatic head of the reservoir is imposed on the gas in the cavity. When load requirements are high gas is withdrawn from the subterranean cavity under the hydrostatic head of the water pressure and used to operate an air motor or other auxiliary prime mover which in turn drives generating equipment. The gas reservoir is maintained under substantially constant pressure.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic view partly in elevation and partly in cross-section illustrating the invention in which separate wells are used for injection and withdrawal of gas;

Figure 2 is a similar view illustrating the invention using a single well for both injection and withdrawal;

Figure 3 is an elevational view illustrating that aspect of the invention in which gas is stored in a subterranean salt cavity under the hydrostatic pressure of a water reservoir at the surface of the ground, showing the reservoir during the period when air is being forced under pressure into the cavity; and

Figure 4 is another elevational view similar to that of figure 3 except that it illustrates the salt cavity during withdrawal of gas to drive one or more auxiliary air motors to operate electrical generating equipment.

Referring to figure 1, the numeral 1 indicates a subterranean reservoir of relatively high porosity and permeability. The reservoir can be a petroleum-barren aquifer, that is, a geological dome or anticline in which no commercial quantity of oil or gas has been produced prior to the storage operation, or the facility may be a depleted oil or gas field. It is an essential characteristic of the aquifer storage reservoir that it have a tight cap rock over the reservoir in order to prevent leakage of gas therefrom. A description of suitable gas storage reservoirs and the methods by which they are evaluated was presented in paper No. SPE 162 entitled, "Evaluation of Underground Gas Storage conditions in Aquifers through Investigation of Groundwater in Hydrology. "delivered before the Society of Petroleum Engineers of AIME during the 30th Annual Fall Meeting in Dallas, Texas, U.S.A. October 1961. The requirements for suitable underground storage reservoirs are set forth in U.S. Bureau of Mines Circular 77654, in Section XXV, entitled, "Underground Storage of Natural Gas in Coal-Mining Areas", by Wheeler and Eckard, particularly at pages 6 and 7. It is preferred but not essential that the type of confined porous rock reservoir be of the type fre-

quently referred to as a "water sand", i.e. a storage reservoir freely interconnected with a confined hydrological system under hydrostatic pressure. Storage of gas in water and reservoirs, as described by Douglas Ball and Peter Burnett in the paper "Storage of Gas in Water Sands", pages 68—72, the Mines Magazine, Vol. 49, November 1959, is particularly desirable because of the pressure normalizing effect of the hydrological system. At reservoir locations where geological structures persist through a thick sequence of strata several suitable reservoir strata may exist and permit simultaneous storage operations in more than one strata. When multiple zone storage is utilized an exchange or recycling of gas from one zone to another may be desirable to improve or maintain efficiencies of the storage system. Where multiple zone storage is used, air or other suitable gas is compressed and stored in a low pressure aquifer reservoir under hydrostatic pressure of about 2812 to 10,545 grams per square centimeter. This air is then compressed, using excess electrical power during off peak or low load periods, to about 5625 to 105,450 grams per square centimeter and transferred to and stored in a substantially constant pressure aquifer reservoir existing under hydrostatic pressure of the same magnitude. The air from the high pressure reservoir is used to drive the air motor and the air released is returned to the low pressure reservoir in a manner similar to U.S. patent No. 942,411. By using multiple zone-multiple pressure storage reservoirs, the need for multistage compression and expansion is eliminated, equipment cost is reduced and efficiency is increased. Such a multiple zone underground gas storage system is operated by Natural Gas Storage Company of Illinois at Herscher, Illinois and described in "Underground Storage of Natural Gas in Illinois", by Alfred H. Bell and published by Illinois State Geological Survey, 1961, Circular 318.

Referring to figure 1, the numeral 3 represents the cap rock of shale or other gas impermeable rock which overlies the aquifer or other storage reservoir 1. The numeral 5 represents an injection well, and the numeral 7 represents the withdrawal or output well. Air or other gas is fed through line 9 to compressor 11 and injected through well 5 under pressure sufficiently high to overcome the hydrostatic pressure in the reservoir. For example, if the hydrostatic pressure in the reservoir is 17,577 gm/sq.cm., the air will be compressed to a pressure exceeding the hydrostatic pressure by a factor at least sufficient to initiate displacement of the water. Generally, a pressure excess of 10 per cent will be sufficient.

Air compressor 11 is operated by electricity supplied from a power plant such as a hydroelectric or steam generating plant. In practice, air is compressed and injected through well 5 only during periods of off-peak load when the demand for electricity is below the capacity of the hydroelectric or steam generating plant.

Air stored in the reservoir 1 under existing hydrostatic pressure is withdrawn through line 7 as required. Withdrawal may be simultaneous with injection, or may occur only during periods when air is not being injected, depending on the purpose for which the withdrawn air is used. For example, if the air is used for electric generating purposes other than at the power plant, it may be withdrawn at any time that the load requirements dictate. On the other hand, if the air is to be used to motivate additional electrical generating equipment during periods of peak load, the air will be withdrawn during high load periods when air is not being injected through well 5, since the electrical generating capacity will be required to meet the electrical demand and will not be available for compressing air for injection into the reservoir. If the system is used for supplementing the output of a hydroelectric, steam or diesel engine or other electrical generating plant during high load periods, injection and withdrawal of gas can be effected through a single well.

Air or other gas withdrawn through well 7 can be used to motivate a prime mover 13 such as a turbine or air motor which, in turn, can be made to drive additional electrical generating equipment 15. Suitable air motors for driving electrical generators are described at pp. 275 to 305 of "Compressed Air Plant", 5th Ed., by Robert Peele, published 1930 by John Wiley & Sons, New York.

An alternative to the described method is that illustrated in figure 2 in which one well 16 serves both for injection and withdrawal of the compressed gas and a combination compressor-air motor 17 is used both for compression and also gas expansion to drive generator 15. One such device, the rotary screw, which will serve for the air compression and the air motor to drive the generator, is described by Whitehouse, Council and Martinez, in "Peaking Power with Air", Power Engineering, January 1968, pp. 50—52.

Rock strata having a porosity of at least 6 per cent and as high as 40 per cent, and a permeability of at least 5 millidarcies and as high as 50,000 millidarcies, are suitable for the purposes of my invention. The formation should be of sufficient areal extent and thickness to accept the required amount of gas necessary to power the auxiliary equipment for the particular power plant. Such reservoirs may be porous and permeable sandstone beds, reefs or reef breccias confined, at least superjacently, by impermeable beds. The reservoir should also be such that lateral movement of the compressed air or other gas is restricted to the extent that it can be reclaimed.

Such lateral restriction can be found in the case of folds, domes, faults or pinching out of permeable strata, reefs or reef breccias, or occasionally in horizontal formations without domes.

As previously pointed out, in accordance with the invention, the subterranean reservoir must be one which is capable of accepting the quantities of gas required to enable the integrated power plant to operate at maximum efficiency without substantially increasing or suffering a significant loss in pressure during withdrawal.

The invention herein described has the following advantages over the elevated surface water reservoir method of utilizing excess electrical energy and reclaiming it through the use of water turbines:

(a) The invention is not dependent on adequate topographic relief which is required in the elevated surface water system in order to acquire the required head of water to drive the turbine.

(b) Surface water reservoirs are frequently very expensive, difficult to construct and seal and give rise to evaporation losses, whereas underground reservoirs are found in widely dispersed areas of the United States. Because water is a valuable commodity, two surface reservoirs are generally required—one at a high elevation and the other at a low elevation so that water is conserved and readily available. An air storage peaking system, on the other hand, requires only one reservoir because atmospheric air is universally available. Moreover, it is practical to utilize a reservoir at some distance from the generating plant since the gas can be readily piped from the reservoir to the plant.

(c) In some areas where electrical power is generated there is inadequate water supply to support an elevated surface water system.

(d) By reason of the fact that the air or other gas is withdrawn from the reservoir under substantially constant hydrostatic pressure, substantially all the gas under storage can be used to drive the air motors. This fact enables the use of smaller cavities and lower capital costs than would otherwise be necessitated if the gas were withdrawn under gradually decreasing pressure and as a result thereof only part of the stored gas could be used since withdrawal would have to be discontinued when the pressure dropped below the operating pressure of the air motors.

(e) In addition to the advantages previously mentioned, my invention provides a reservoir that automatically expands and contracts to the desired volume without signaficant pressure change.

While aquifer-type storage is considerably cheaper than storage in washed cavities in bedded or domed rock salt, salt cavity storage as practiced in accordance with this invention offers considerable economic advantage over present methods of salt cavity storage and therefore provide a desirable method of producing auxiliary power in those locations where there is no natural aquifer reservoir but where salt beds or domes are present.

The aquifer type storage of the present invention has the advantage over present methods for the use of mined or washed-out salt cavities in the earth as storage reservoirs in that in the latter, air or gas has to be pumped into the fixed volume reservoir which is at substantially atmospheric pressure and as a result loss of pressure is suffered until enough gas is pumped in to build the pressure up to the injection pressure. Either the pressure in the cavity will have to be built up to considerably above the required pressure for driving the generating facilities, or only a small portion of the stored gas can be used because of the rapid drop in pressure upon withdrawal of the gas from the cavity. On the other hand, where the gas is stored against natural hydrostatic pressure, storage pressures will be at a finite level adequate to drive gas turbines, air motors or other electrical generating equipment and injection and withdrawal of gas from the rock will not significantly vary the existing pressure of the reservoir.

The following example shows the cost of developing gas storage in an underground aquifer for a practical auxiliary power installation to take care of peak loads.

Assume:

Working pressure	—50,270 grams per sq.cm. gauge
Peak day withdrawal	—18.408×10^6 cu.m.

Then:

Gas unit weight of air=1.2 Kg./cu.m.

Weight of 18.408×10^6 cu.m.$=18.408 \times 10^6 \times 1.2 = 22.1 \times 10^6$ Kgs./day

Average Kgs. per hr. of air required$=22.1 \times 10^6 \div 24 = 0.923 \times 10^6$

Pressure differential to expander=49.216 Kg. per sq. m.

(pressure of gas above atm.)$\times 10{,}000$ (sq.cm./sq.m.)$\div 1.2$

(wt. of 1 cu. m. of gas)$=.439 \times 10^6$ m. of gas

Average metric gas horsepower at 70% efficiency$=0.923 \times 10^6 \div 60$(min./hr.) $\times (.439 \times 10^6 \div 4500) \times 0.70 = 1.051 \times 10^6$

Average KW output$=1.051 \times 10^6 \times 0.735 =$ 772,000

aic advan-
avity stor-
ble method
those loca-
uifer reser-
s are pre-

he present
r present
washed-out
: reservoirs
has to be
voir which
essure and
fered until
l the pres-
Either the
o be built
uired pres-
cilities, or
gas can be
n pressure
the cavity.
s is stored
re, storage
dequate to
other elec-
jection and
l not signi-
f the reser-

he cost of
nderground
wer instal-
s.

grams per
gauge
$\times 10^6$ cu.m.

cu.m.

$=18.408\times$
y

ed$=22.1\times$

ler$=49.216$

n.)$\times 10{,}000$

$\times 10^6$ m. of

t 70% effi-
nin./hr.) $\times$
051$\times 10^6$

)$^6\times 0.735=$

A reservoir can be safely operated within the range of between 0.3 and 9 to 1 cushion-to-working gas ratio. Thus, if this storage is used three hours per day to supply auxiliary power, 18.408×10^6 c.m.$\div 8$ or 2.3×10^6 c.m. of gas will be withdrawn thus necessitating a reservoir capacity of 23×10^6 c.m. At $18.77 per 10^3 c.m. (published cost for development of gas storage of this type), the cost for the reservoir would be about $430,000 or $0.58 per KW as compared with 40% of $85—$150/KW (published figure) for hydro-storage construction costs.

Referring now to figures 3 and 4, the numeral 21 indicates a well bore extending from the surface of the ground to a cavity 23 formed in a subterranean impermeable rock or salt formation 25. Cavity 23 may be formed either by mechanical mining operation or by solution extraction of the salt from the salt bed. The bore is cased with corrosion resistent casing 26 made of steel or other suitable material and cemented in place. A pipe 27 extends from the surface through well bore 21 to the bottom of the cavity 23. Aqueous reservoir 29 is constructed at a surface of the earth so that the upper end of pipe 27 opens into or is connected to the lower portion of the reservoir. The capacity of the water reservoir is preferably about the same as the gas reservoir although it may be larger or smaller. The volume of the gas cavern will depend on the requirements for auxiliary power.

The upper end of bore 21 is closed and connected by pipe line 31 controlled by valve 33 to a motor 35 operable on compressed air. It is preferred to use a reversible air compressor-air motor so that the same facility can be used to inject compressed air into the subterranean cavity or storage reservoir.

The air compressor 35 is used to drive motor-generator 37 which generates the electricity required for peak load conditions.

During those periods when the main power plant is operating under partial load, the excess electrical capacity is used to energize the motor-generator which drives the air compressor or reversible air compressor-air motor 35 to compress air and inject it through lines 31 and bore 21 into the subterranean reservoir 23 against the hydrostatic head of water in pipe 27, thereby forcing the water in the cavity or reservoir up through the pipe 27 into reservoir 29 as shown in Figure 3.

During periods of peak load when the capacity of the main prime mover in the power plant has been reached, air is withdrawn from the reservoir 23 through bore 21, pipe 31 and valve 33 to drive the air motor or reversible air compressor-air motor 35 which in turn operates generator 37 to generate the additional electrical power required.

It will be apparent that by closing valve 33 the reservoir system can be made to assume a static condition in which air is neither withdrawn from nor injected into the reservoir.

The height of the water column in pipe 27 will determine the pressure under which air or other gas is stored in the underground reservoir 23. Although gas at pressures of about 2812 to 103,450 grams per square centimeter is usable, it is preferred to store the gas at a pressure of approximately 7,030 to 84,370 grams per square centimeter. It is preferred to use as high pressure storage as possible for the reason that the higher the pressure at which the air or the gas is stored, the smaller is the cavity and surface reservoir size required for a given generating capacity. Furthermore, by using high pressure storage the air can be pumped into the storage in a shorter period of time and this can be important where the low load periods are short as compared with the peak load periods. It will be apparent that the gas can be withdrawn from storage to operate the air motor or prime mover either at the storage pressure or at a reduced pressure by partially opening valve 33.

The upper limit of pressure which is practicable for storing air or other gas is determined by the solution of the gas in the water or other aqueous liquid. The amount of gas which will dissolve is dependent on the nature of the gas fluid phase, temperature and pressure. While solution of gas in saturated sodium chloride brine is not nearly as serious as in water because of lower solubility, where the pressure is too high large amounts of gas dissolve in the water or brine and are carried to the surface and released at atmospheric pressure, thereby resulting in a large energy loss. It is important, therefore, to keep the storage pressure below that at which significant amounts of air or other gas dissolve in the brine or aqueous liquid. When using air and brine it has been found that pressure between approximately 17,577 and 52,731 grams per square centimeter are satisfactory. During injection of compressed gas into the reservoir 23, water or brine is forced from the reservoir up through pipe or tubing 27 into reservoir 29 and is displaced by the compressed gas which is maintained under the hydrostatic head of the water or brine in pipe 27. Obviously, a separate well bore may be used for gas injection and withdrawal from the underground cavity and for flow of water or brine between the underground cavity and surface reservoir. The system operates under very small pressure defferentials and performs for all practical purposes as a variable volume-constant pressure storage reservoir. The system will accept gas at any pressure exceeding the hydrostatic pressure but will deliver gas at a constant pressure and rate until the total amount of gas is depleted from the reservoir. Because of the substantially constant pressure of the gas in the subterranean reservoir, the entire gas storage volume is usable for driv-

ing generating equipment and for that reason much smaller reservoir capacity is needed than in the case where straight gas storage is used. A further advantage of the present system over straight gas storage is that when a salt cavity is employed as a reservoir, the periodic wetting of the cavity by the brine aids in sealing fractures and permeable zones in the rock salt wall, thereby preventing loss of compressed gas. Furthermore, because of the fact there is little or no pressure variation in the reservoir the likelihood of collapse of the roof structure is mitigated.

The invention has a considerable advantage over conventional pumped-storage in that large savings in capital costs are possible. In an article entitled, "How to Evaluate Pumped Storage for Peak in Generation", by John Pitt, published in the July 1964 issue of Power Engineering, pages 28 to 32 inclusive, it is disclosed that the cost of pumped storage is upward of $80 per kilowatt. The cost of creating underground storage in a salt cavity is comparatively cheap as disclosed at page 2 of the aforementioned Information Circular 77654, Section XXV, page 2, in an article entitled, "Underground Storage of Natural Gas in Coal-Mining Areas", by Wheeler and Eckard. By being able to construct a relatively small reservoir at ground level instead of having to construct a reservoir at an elevation considerably above the power plant a very significant saving in capital cost is effected. The combined saving due to smaller gas cavern size and location of the water reservoir results in a large capital cost reduction.

Although the invention has been described with particular reference to storage and use of air for driving air motors to generate additional electrical power, it should be understood that other gases such as carbon dioxide and natural gas, and gases such as LPG which are liquid under pressure can be stored under pressure for use ir operating a prime mover for driving power generating equipment.

As an example of the above described system of the invention, a cavity having a volume of 311,487 cubic meters was prepared in a rock salt formation by solution washing at a depth of 260 meters from the surface to the bottom of the cavity. A concrete reservoir is constructed immediately adjacent to the well bore at ground surface, the reservoir having approximately the same volumetric storage capacity as the subsurface cavity. The air in the cavity is stored under a gage pressure of 31,076 grams per square centimeter, equal to a hydrostatic column of saturated brine of 260 meters. Under these conditions, the gas storage capacity will be about 9,344,610 cubic meters measured at standard temperature and pressure. Air is pumped into the cavity displacing brine to the surface reservoir at a pressure exceeding the hydrostatic pressure by a few kilograms per square centimeter, or at greater pressures if high injection rate is desired. The air is withdrawn from the cavity at a pressure of 31,076 grams per square centimeter at a rate of 1962 cubic meters per minute at the inlet of a reversible compressor-air motor which, in turn, drives a generator which is capable of generating about 67,000 Kw for a maximum of 79 hours or a total of 5,300,000 Kw hours. The storage is used to provide emergency power or peaking power for daily or weekly cycles.

The reservoir is always at high pressure at the time it is being filled and therefore a high amount of energy is expanded to fill the reservoir during short periods when excess capacity (low load) is available. This aids in stabilizing the load on the system.

Moreover, during storage the gas becomes saturated with water vapor and as a result the horsepower produced will be greater than that required to inject relatively dry air into the formation.

It will be seen, therefore, that a method and system are provided for providing power at much lower cost than is possible by presently known methods, due to the low cost of storage and the increased power output of the stored gas.

WHAT I CLAIM IS:—

1. A method for conserving energy in which gas is compressed and stored in a subterranean reservoir by means of electric power during periods of relatively low electrical load requirement and the gas stored under pressure is withdrawn and used to drive a prime mover to generate electricity during periods of relatively high electrical load requirement, characterized by the fact that the gas is introduced into, stored in and withdrawn from the reservoir while it is held under hydrostatic pressure which does not significantly change and which is sufficient to drive the prime mover.

2. Method in accordance with claim 1 in which the subterranean reservoir is an aquifer with a gas-impermeable cap rock.

3. Method in accordance with claim 2 in which the aquifer exists under a natural hydrostatic pressure of between about 17,577 gm/sq.cm. and about 210,000 gm/sq.cm.

4. Method in accordance with any of the preceding claims in which the gas in injected into and withdrawn from the reservoir through separate conduits.

5. Method in accordance with either claim 2 or claim 3 in which the aquifer has a porosity of not less than about 10 per cent and a permeability of not less than about 5 millidarcies.

6. Method in accordance with claims 1 to 5 in which the gas is stored in more than one

subterranean reservoir under different pressures, the gas from a lower pressure reservoir is compressed by means of excess electric power during periods of relatively low load requirement to the pressure of a higher pressure reservoir and stored therein, the gas from the higher pressure reservoir is used to drive the prime mover, the gas from the prime mover is exhausted at a pressure above the lower pressure reservoir and returned to the lower pressure reservoir without compression.

7. The method in accordance with claim 6 in which the gas is first stored in a lower pressure reservoir at about 2812 to 10546 grams per square centimeter and transferred from the lower pressure reservoir to a higher pressure reservoir at about 5625 to 105460 grams per square centimeter.

8. The method in accordance with claim 1 in which the subterranean reservoir is substantially gas impermeable and the gas is held under substantially constant hydrostatic pressure by means of aqueous liquid in a reservoir at the ground level connected by a confined column of water with aqueous liquid in said subterranean reservoir.

9. The method in accordance with claim 1 or 8 in which the subterranean reservoir is a washed out cavity in a salt bed.

10. The method in accordance with any of the preceding claims in which the gas is air.

11. A method for conserving energy substantially as herein described with reference to the accompanying drawings.

12. A system for conserving energy comprising at least one subterranean storage reservoir, an electrical generating facility, a gas compressor motivated by electricity from said facility, a conduit extending from said reservoir to the surface thereabove for injecting gas from said compressor into said reservoir, means for withdrawing gas from the reservoir, a prime mover operatively connected to the withdrawn gas, and electrical generating means operatively connected to said prime mover, characterized by means for maintaining said reservoir under superatmospheric hydrostatic pressure which does not change significantly during injection, storage and withdrawal of the gas.

13. A system in accordance with claim 12 in which the last mentioned means is an aquifer of relatively high porosity and permeability with a gas impermeable cap rock.

14. A system in accordance with claim 13 in which said aquifer has a natural hydrostatic pressure of between about 17,577 gm/sq.cm. and about 210,000 gm/sq.cm.

15. A system in accordance with either claim 13 or claim 14 in which the aquifer has a porosity of not less than about 10 per cent and a permeability of not less than about 5 millidarcies.

16. A system in accordance with claim 12 in which the last mentioned means is a reservoir of aqueous liquid at the aforesaid surface connected by a column of confined aqueous liquid to aqueous liquid in the reservoir.

17. A system in accordance with claim 12 or 16 in which the subterranean storage reservoir is a cavity in a washed out salt bed.

18. Apparatus for conserving energy substantially as herein described with reference to the accompanying drawings.

A. A. THORNTON & CO.,
Northumberland House,
303—306 High Holborn,
London, W.C.1.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1970.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

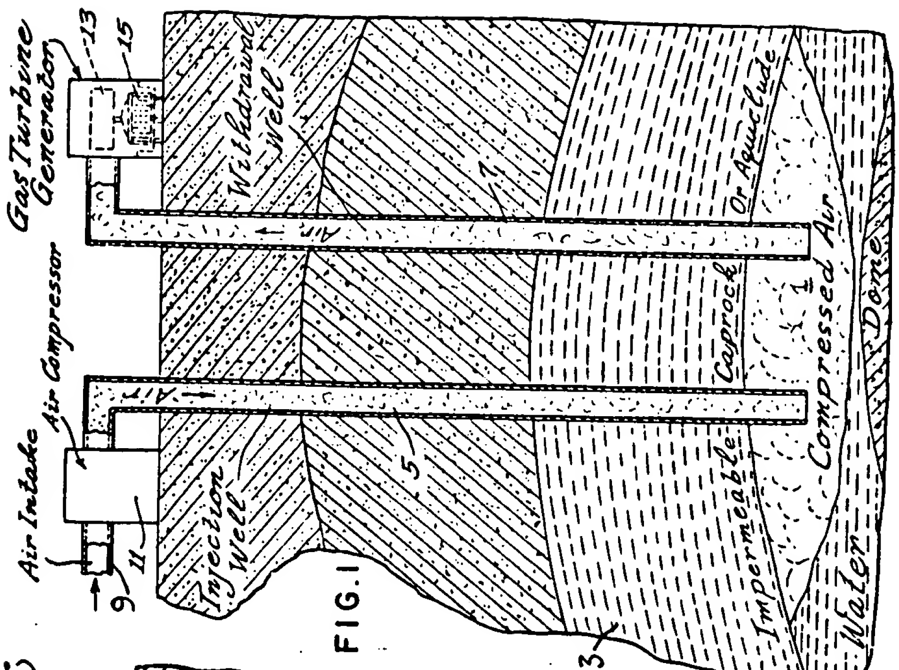
Gas Turbine Generator
13
15
Withdrawal well
7
Air Compressor
Air Intake
9
11
Injection well
5
3
Caprock
Or Aquiclude
Impermeable
Compressed Air
1
Water
Dome

FIG. 1

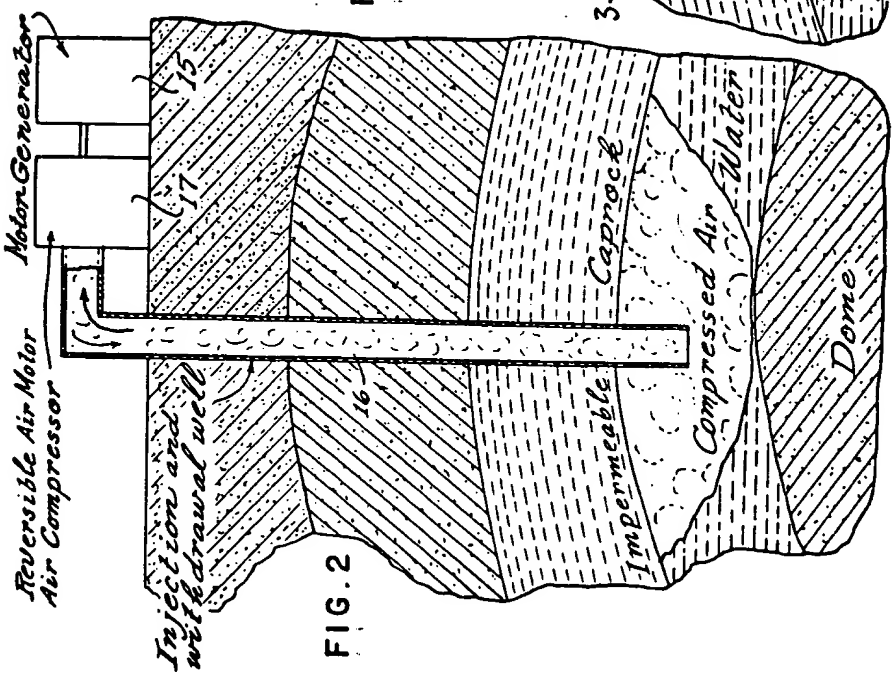
Motor Generator
15
17
Reversible Air Motor
Air Compressor
Injection and withdrawal well
16
Caprock
Impermeable
Compressed Air
Water
Dome

FIG. 2

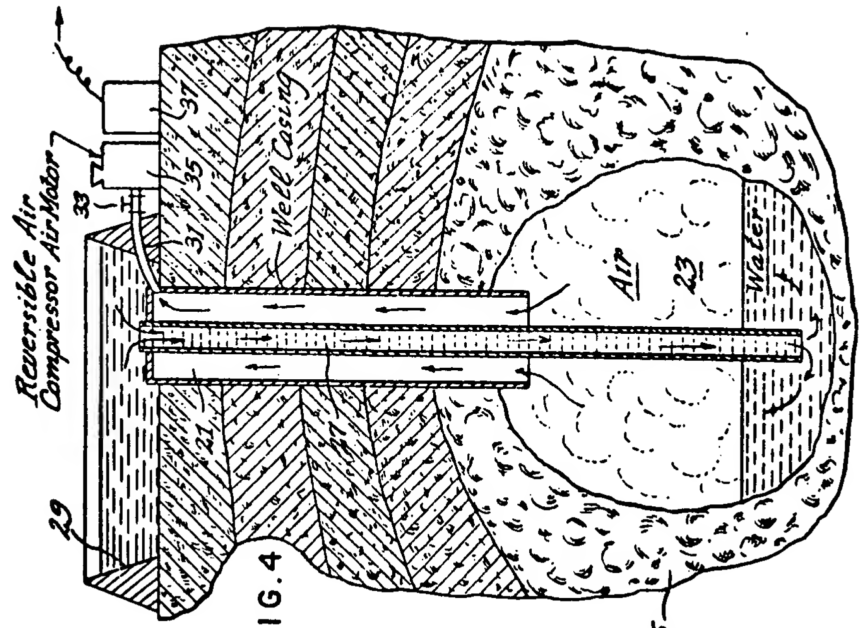
Reversible Air Compressor Air Motor
33
35
37
37
31
Well Casing
21
27
29
Air
23
Water
25

FIG. 4

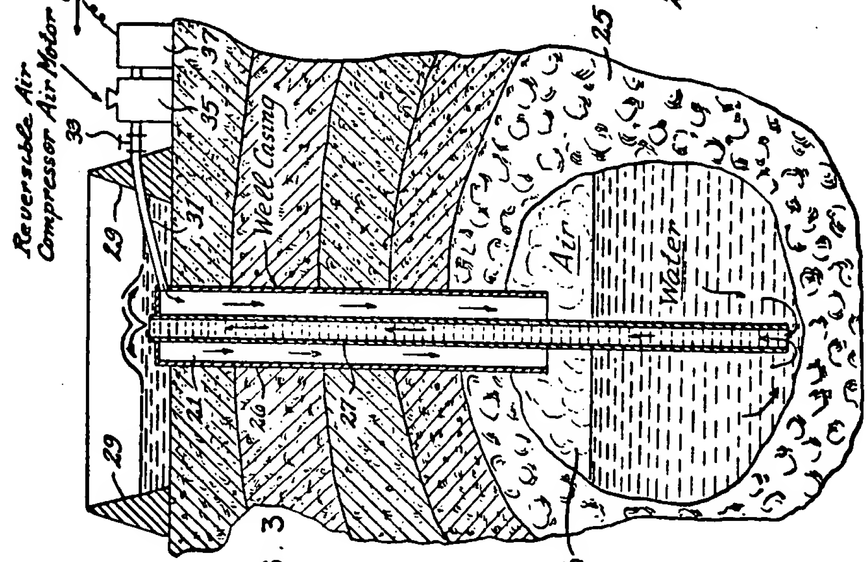
Reversible Air Compressor Air Motor
C
33
35
37
31
29
29
Well Casing
21
26
27
Air
Water
25
25

FIG. 3